4 LIMITING FACTORS

The causes for decline of Lake Ozette sockeye are numerous and not entirely understood, although several hypotheses were proposed prior to the initiation of the current recovery planning effort (e.g., Jacobs et al. 1996, Gustafson et al. 1997, and MFM 2000). Makah Fisheries Management (2000) summarized the commonly presented factors for decline as follows: (1) loss of adequate quality and quantity of beach spawning habitat; (2) loss of tributary spawning sockeye populations; (3) past over-exploitation; (4) predation and disruption of natural predator-prey relationships; (5) introduction of non-native fish and plant species; (6) temporarily poor ocean conditions; and (7) interactions of these factors. The collective effects of these factors may have further influenced spawning habitat quality by reducing the population size to a threshold where lower densities of spawning fish could not adequately maintain clean, vegetation-free spawning gravels. The introduction of non-native plant and fish species may currently affect the population's ability to recover, but there is currently little evidence to implicate non-native species as an important factor responsible for the decline of Lake Ozette sockeye.

It is important to distinguish between factors responsible for the decline of the population (factors for decline), and factors that currently limit sockeye abundance and productivity (limiting factors), as they are not necessarily one and the same. Certain activities that may have contributed to the decline of Ozette sockeye may no longer operate to limit abundance or productivity (e.g., commercial sockeye harvest).

A more thorough identification of limiting factors hypothesized as currently affecting Lake Ozette sockeye was completed recently and is described in detail in the Lake Ozette Sockeye Limiting Factors Analysis (LFA) (Haggerty et al. 2007). Based on the best available information and analysis, the Lake Ozette Steering Committee's Technical Workgroup evaluated and rated each of the limiting factors hypotheses for its contribution to sockeye population or subpopulation mortality by life stage. The degree of impact of each limiting factor hypothesis was categorized as one of the following: unknown, negligible, low, moderate, or high. Sections 4.1 through 4.4 present a summary of the findings from the Lake Ozette Sockeye LFA (for detailed explanations and evidence for each limiting factor and life stage, please refer to the LFA). Figure 4.1 and Figure 4.2 are simplified depictions of these limiting factor ratings. The figures illustrate the estimated relative mortality thought to be associated with each hypothesized limiting factor for sockeye salmon by subpopulation and life stage.

Limiting factors affecting Lake Ozette sockeye are presented in this plan as a series of hypotheses that can be tested. The adaptive management program will include monitoring and evaluation designed to yield information confirming or disconfirming these hypotheses; this information, in turn, will become feedback to management on the effectiveness of recovery strategies and actions.

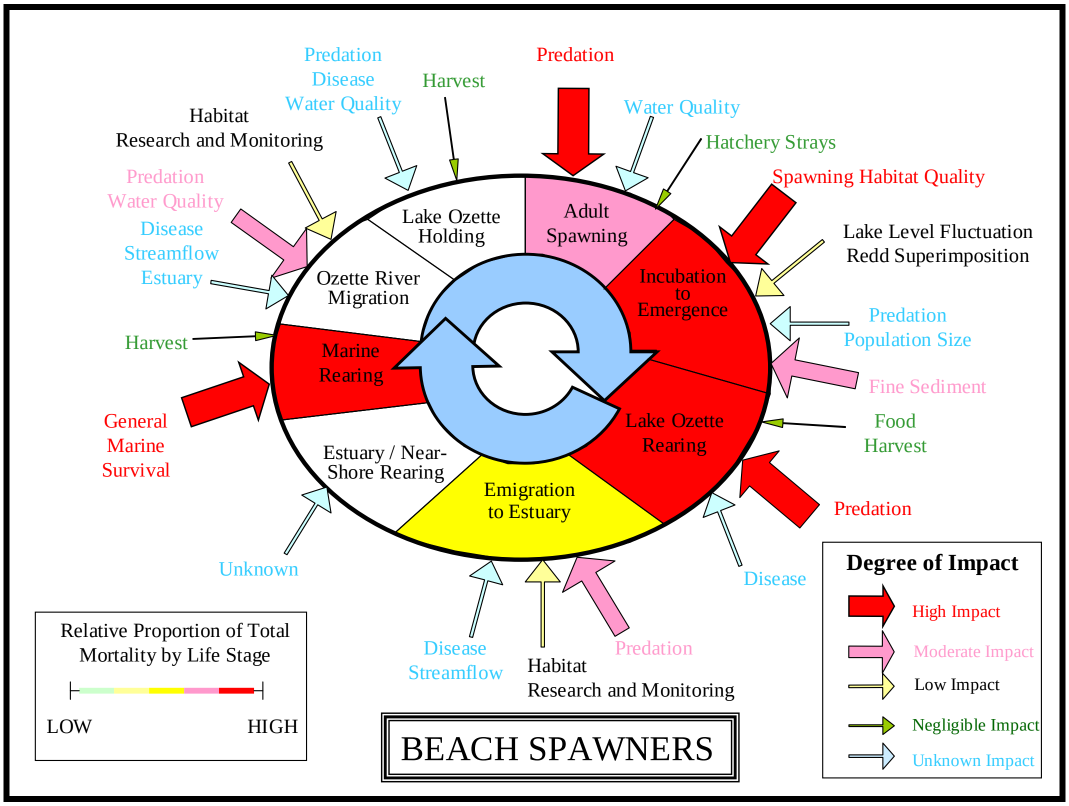

Figure 4.1. Beach spawning sockeye life history stages and hypothesized limiting factors.

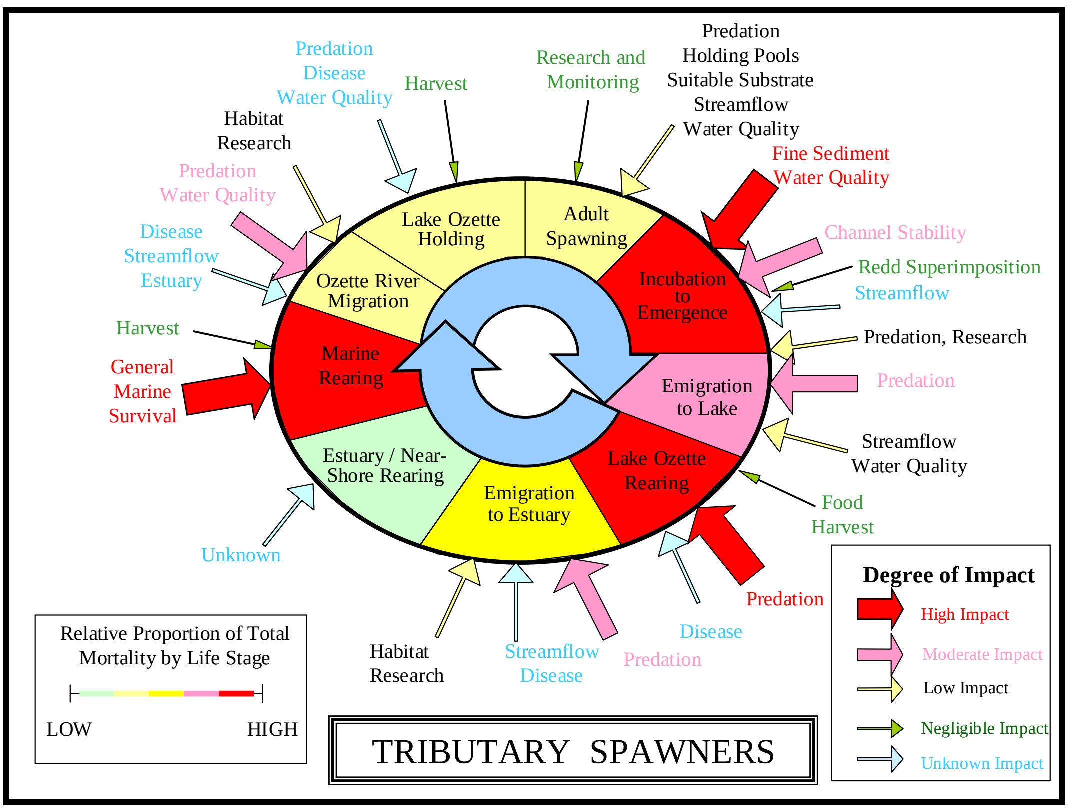

Figure 4.2. Tributary spawning sockeye life history stages and hypothesized limiting factors.

4.1 LIMITING FACTORS APPROACH

Identifying, rating, and describing the factors that limit the productivity and abundance of the species in question enables recovery planners to identify actions, management scenarios, and activities that, in turn, may reduce the limiting factors and help to rebuild the population(s). The Limiting Factors Analysis (Haggerty et al. 2007) identified and rated limiting factors based upon the degree of impact and relative mortality by life stage that directly results from a given phenomenon. The LFA method of identifying limiting factors differed significantly from methods used in other limiting factors analyses conducted within the Puget Sound recovery domain. In these other limiting factors analyses, biologists and planners identified factors that had been altered through various human management practices (e.g., land use, fisheries, hatcheries) and typically did not include intrinsic factors (e.g., marine survival and/or predation) that limit the productivity and abundance of salmonids. In contrast, the approach used in the Lake Ozette Sockeye LFA included both intrinsic limiting factors and anthropogenically influenced limiting factors.

Within the LFA and this recovery plan we assume that the historical (pre-European development) intrinsic factors that “naturally” limited sockeye abundance, productivity, spatial structure, and diversity resulted in a viable sockeye salmon population. Furthermore we assume that in historical times, since Euro-American homesteading began in the watershed, human activities have changed the watershed and ecosystem in which sockeye salmon were once viable by altering the physical features and biological processes that create sockeye salmon habitat at the population and subpopulation scale. These physical and biological alterations have resulted in decreased sockeye viability by reducing the abundance, productivity, spatial structure, and diversity of Ozette sockeye. Past, present, and future actions that affect the physical and biological state of the watershed have the potential to further decrease the viability of Lake Ozette sockeye. In order to develop critical insight into how to improve the physical and biological conditions affecting the viability of Ozette sockeye, the LFA and this recovery plan identify the limiting factors currently affecting sockeye, the processes and inputs that create the limiting factors, and the activities (past and present) that alter inputs and processes.

The Lake Ozette sockeye salmon ESU is composed of one population (PSTRT 2006) and contains five known spawning aggregations. Each spawning aggregation represents an individual subpopulation. Some limiting factors, habitat conditions, and life histories are shared among all subpopulations, while others vary among them. In the LFA, the subpopulations were grouped based on spawning environment, i.e. tributary vs. beach, and limiting factors were described in three categories: those affecting the entire population; those specific to beach spawners; and those specific to tributary spawners. This approach is also used in the recovery plan. Limiting factors identified for each of these three categories are assigned into one of three further categories, reflecting their relative standing as ***Key*** limiting factors, ***Contributing*** limiting factors, or factors ***Not Likely*** limiting.

- ***Key*** limiting factors are those with the greatest impact on the population's ability to reach its desired status. Key limiting factors directly result in decreased sockeye salmon viability, because of the degree of impact, frequency and persistence of impact, and/or scale of population affected. A key limiting factor required high ratings in both the degree of impact on sockeye and the relative mortality during at least one life history stage. In addition, conditions influencing the factor must have a significant linkage to anthropogenically influenced processes and inputs.
- ***Contributing*** limiting factors also influence survival and/or directly result in the mortality of sockeye salmon. Contributing limiting factors are likely to cumulatively or individually result in decreased sockeye salmon viability, because of the degree of impact, frequency and persistence of impact, and/or scale of population affected, but the degree of impact is rated low, moderate, or unknown.
- ***Factors not likely limiting*** can influence the survival or directly result in the mortality of individual sockeye salmon, but because of the scale of influence, either by degree of impact or scale of population affected, they are not likely to cumulatively or individually result in decreased sockeye salmon viability. The degree of impact is rated low, negligible, or unknown.

Several parameters regulating and/or affecting each key and contributing limiting factor are described and evaluated in subsections 4.2 through 4.4. Each limiting factor is presented in a structured system that includes five parts: life history stages affected, limiting factor hypothesis, limiting factor rationale, description of processes and inputs regulating limiting factor, and activities and/or conditions affecting processes and inputs.

The limiting factor hypotheses were simplified to make the recovery plan more accessible to a wider audience. Details are available in the Limiting Factors Analysis (Haggerty et al. 2007). Whereas the hypotheses in the Limiting Factors Analysis were logically split up into the smallest possible units of verifiable assertions, for the recovery plan they were combined (lumped) into new single hypotheses that would cover either an entire population segment or the entire sockeye population.

For example, Hypothesis 1 in the recovery plan states that predation on sockeye salmon in recent times is higher than it used to be, probably because of changes in relative numbers of sockeye and predators. In the Limiting Factors Analysis, this general statement relating to all life stages of sockeye and all subpopulations is broken down into life history stages and locations: adult sockeye in the Ozette River heading for the lake; adult sockeye holding in the lake before spawning; juvenile sockeye rearing in the lake; juvenile sockeye in the Ozette River heading for the ocean. Each of these categories in turn may have several "sub-hypotheses" about specific causes for higher predation in specific situations.

Recovery plan hypotheses are numbered 1 through 16 according to the order in which they are presented. Numbering does not indicate importance, priority, or rank. Table 4.1 includes a summary of each limiting factor hypothesis presented in Sections 4.2 to 4.4 of the recovery plan and a link to the related hypotheses in Haggerty et al. (2007).

Habitat-forming processes and inputs that may regulate limiting factors within the watershed are also identified in Sections 4.2 to 4.4. Examples of habitat-forming processes and inputs include but are not limited to the following: riparian community succession and organic inputs, sediment delivery and bedload storage and transport, precipitation runoff patterns, channel migration, predator-prey food-web interactions, and thermal and chemical inputs. Habitat-forming processes and inputs affecting limiting factor hypotheses were identified based on best available information for the Lake Ozette watershed. Finally, land use and other activities that affect natural habitat-forming processes and inputs are also identified within Chapter 4. For each limiting factor hypothesis presented, the linkage between habitat-forming processes and inputs is presented, as well as the known anthropogenic activities that affect the natural rate, quantity, or pathway of habitat-forming processes and inputs. Understanding the linkage between limiting factors, processes and inputs, and activities that alter natural habitat-forming processes and inputs is critical in the development of strategies aimed at recovering the conditions that limit VSP parameters. A monitoring and evaluation plan structured as part of an adaptive management program makes it possible to adjust the course of recovery actions as our understanding increases.

Table 4.1. Summary of limiting factors hypotheses presented and links to limiting factors hypotheses presented in the LFA (Haggerty et al. 2007).

Limiting Factor Hypothesis # Used in Plan	Limiting Factor Hypothesis # in LFA	Limiting Factor Hypothesis Category	Population Segment(s) Affected	Limiting Factor	NARRATIVE
H#1 (Pred)	1, 7, 41, 45	Key	ALL	Predation	Changes in relative predator-prey abundances in the Ozette River and Lake Ozette have increased the proportion of juvenile and adult sockeye consumed by predators and resulted in decreased freshwater survival, as well as an overall decrease in the number of sockeye returning to spawn.
H#2 (WQ)	3, 7, 47	Contributing	ALL	Water Quality	High stream temperatures and low frequency, high intensity turbidity events reduce the fitness of sockeye salmon entering or exiting Lake Ozette and result in decreased survival and productivity.
H#3 (Q)	4, 48	Contributing	ALL	Streamflow	Reduced streamflows in the Ozette River affect water quality and predation rates and efficiency and reduce the fitness of migrating and emigrating sockeye.

Limiting Factor Hypothesis # Used in Plan	Limiting Factor Hypothesis # in LFA	Limiting Factor Hypothesis Category	Population Segment(s) Affected	Limiting Factor	NARRATIVE
H#4 (Hab)	2, 46	Contributing	ALL	Habitat	Reduced pool depth, volume, and cover have decreased predator avoidance capabilities and refuge areas for sockeye, increasing predator efficiency and reducing refuge habitat.
H#5 (MS)	53	Contributing	ALL	Marine Survival	Survival in the marine environment is driven by large-scale climatic processes, which are mostly not controllable. Variability in marine survival rates for sockeye salmon is significant, but not likely a key limiting factor at present. Large-scale changes in marine conditions should be monitored and may be significant in the future.
H#? (EST)	NA	Unknown	ALL	Estuary	Because little is known about the Ozette River estuary, there is no current hypothesis concerning estuarine conditions as a limiting factor for sockeye. This is an important data gap.
H#6 (BSH)	13, 17	Key	Beach Spawners	Spawning Habitat	Reduced quality and quantity of beach spawning habitat in Lake Ozette has decreased egg to emergence survival, resulting in reduced fry production from the beach spawning aggregations.

Limiting Factor Hypothesis # Used in Plan	Limiting Factor Hypothesis # in LFA	Limiting Factor Hypothesis Category	Population Segment(s) Affected	Limiting Factor	NARRATIVE
H#7 (Pred)	11, 18	Key	Beach Spawners	Predation	Changes in relative predator-prey abundances on Ozette spawning beaches have increased the proportion of adult sockeye, eggs, and newly emerged fry consumed by predators, resulting in decreased freshwater survival.
H#8 (WQ)	NA	Contributing	Beach Spawners	Water Quality	Turbidity and suspended sediment concentration (SSC) at Olsen's and Allen's Beaches have a limited effect on sockeye salmon because of the distance of spawning habitat from major sediment sources. However, at historical spawning sites near major tributary outfalls, such as Umbrella Beach, the effects of turbidity and SSC would be expected to be similar to those described in Hypothesis 13.
H#9 (LL)	14	Contributing	Beach Spawners	Lake Level	Seasonal lake level changes result in redd dewatering, decreasing egg-to-fry survival rates.
H#10 (Comp)	15	Contributing	Beach Spawners	Competition	Reduced spawning habitat quality and quantity have increased the competition for suitable habitat at low to moderate spawning escapement levels, resulting in increased redd superimposition and decreased egg-to-fry survival.

Limiting Factor Hypothesis # Used in Plan	Limiting Factor Hypothesis # in LFA	Limiting Factor Hypothesis Category	Population Segment(s) Affected	Limiting Factor	NARRATIVE
H#11 (TSH)	26, 31	Key	Tributary Spawners	Spawning Habitat	Channel simplification and increased sediment production and delivery to streams have decreased the quantity of suitable spawning habitat (i.e., gravel) available to tributary spawning sockeye. Increased levels of fine sediment (<0.85mm) in spawning gravels reduces intra-gravel flow and oxygenation of redds, resulting in decreased egg-to-fry survival.
H#12 (Stab)	32	Contributing	Tributary Spawners	Channel Stability	Decreased channel stability and floodplain alterations have reduced egg-to-fry emergence survival in sockeye tributaries.
H#13 (WQ)	22, 29, 34, 40	Contributing	Tributary Spawners	Water Quality	Elevated turbidity and SSC levels increase stress and reduce sockeye fitness, resulting in increased egg retention rates and pre-spawning mortalities. High levels of turbidity and SSC result in fine sediment deposition in sockeye redds, decreasing egg survival. High levels of turbidity and SSC during the sockeye fry emigration period result in reduced sockeye fry survival, fitness, increased gill abrasion, and altered oxygen uptake.

Limiting Factor Hypothesis # Used in Plan	Limiting Factor Hypothesis # in LFA	Limiting Factor Hypothesis Category	Population Segment(s) Affected	Limiting Factor	NARRATIVE
H#14 (Pred)	19, 24, 36, 38	Contributing	Tributary Spawners	Predation	Predation of sockeye fry during emergence, emigration, and dispersal significantly reduces the number of fry rearing in the pelagic zone of the lake. Predation on adult sockeye and eggs in tributaries occurs at low levels and is not likely a significant limiting factor.
H#15 (Q)	21, 27, 33, 39	Contributing	Tributary Spawners	Streamflow	Natural and anthropogenically influenced streamflow variability (magnitude, frequency, and timing of low and high flows) affects sockeye mortality by: 1) delaying adult migration into tributaries (resulting in more predation, egg retention), 2) limiting where adults spawn in a cross-section (i.e., sequestering spawners in areas where egg scour or desiccation is likely), and/or 3) increasing emigrating fry exposure times in tributaries (resulting in predation, water quality).

Limiting Factor Hypothesis # Used in Plan	Limiting Factor Hypothesis # in LFA	Limiting Factor Hypothesis Category	Population Segment(s) Affected	Limiting Factor	NARRATIVE
H#16 (HP)	20, 25	Not Currently Limiting	Tributary Spawners	Holding Pools	Current holding pool frequency and volume, reduced from historical conditions, appear to be adequate in relation to the current numbers of adult sockeye salmon. However, as the tributary population continues to expand, this factor may begin to exert an influence.

4.2 LIMITING FACTORS AFFECTING ALL POPULATION SEGMENTS

All Lake Ozette sockeye aggregations experience the same habitat conditions and limiting factors during five life history stages: adult migration (Ozette River), adult holding (Lake Ozette), juvenile rearing (Lake Ozette), smolt emigration to the ocean (Ozette River), and marine rearing. The LFA identified and characterized limiting factors by life stage and degree of impact of each limiting factor within each life stage. The results of the LFA for limiting factors affecting all population segments are shown in Figure 4.3. Each limiting factor was assessed based upon the sockeye life stage affected, the process or input influencing the limiting factor, and activities that affect each process and input. A summary of this assessment is included in Figure 4.4. A detailed narrative of key and contributing limiting factors is included in Sections 4.2.1 and 4.2.2.

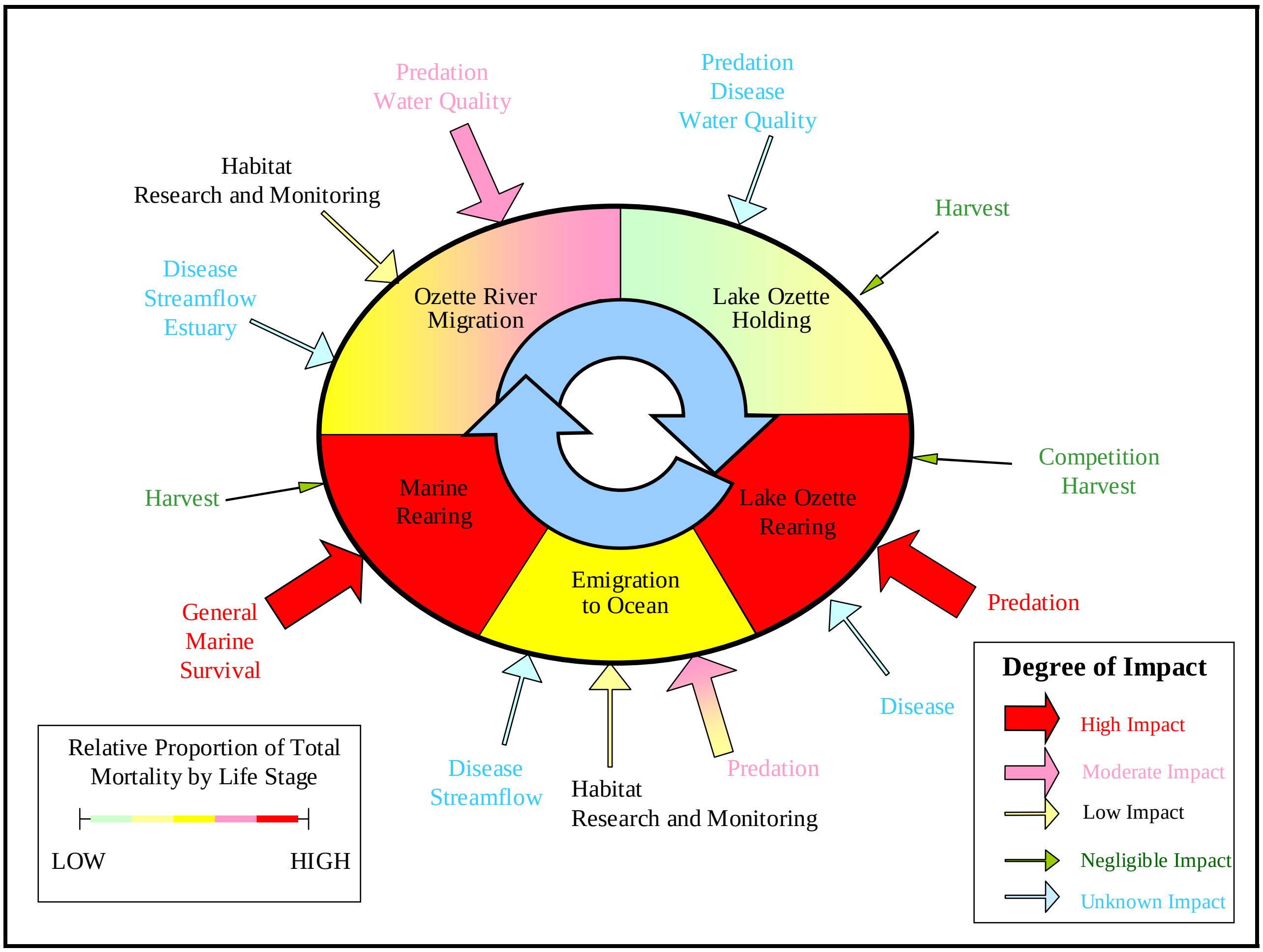

Figure 4.3. Conceptualization of hypothesized limiting factors affecting all Lake Ozette sockeye population segments. Arrows depict the degree of impact for each limiting factor and colored polygons depict the relative proportion of total mortality by life stage.

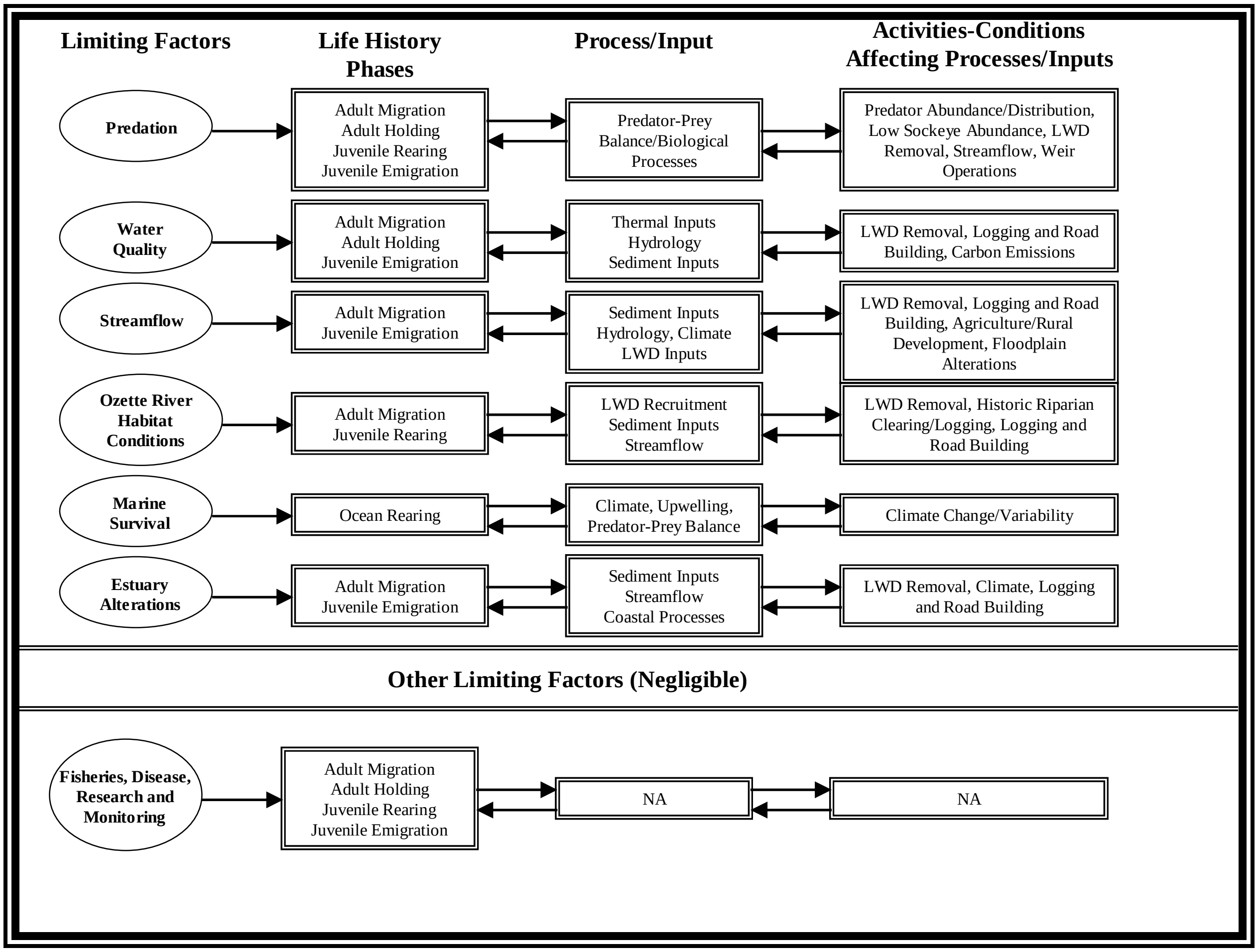

Figure 4.4. Hypothesized limiting factors affecting all population segments, life history phases affected, processes and inputs regulating limiting factors, and activities/conditions affecting processes and inputs.

4.2.1 Key Limiting Factors

Predation is the only key limiting factor identified that affects all population segments.

4.2.1.1 Predation (H#1-Pred)

Hypothesis 1: Changes in relative predator-prey abundances in the Ozette River and Lake Ozette have increased the proportion of juvenile and adult sockeye consumed by predators such as cutthroat trout, northern pikeminnow, largemouth bass, river otters, and harbor seals, and resulted in decreased freshwater survival, as well as an overall decrease in the number of sockeye adults returning to spawn.

Life stages affected: Adult migration, adult holding, juvenile rearing, and juvenile emigration.

Rationale: Sockeye entering Lake Ozette have a high incidence of predator-induced scarring and open wounds (~30-50 percent). A mark and recapture study conducted in 2000 (Gearin et al. 2002) indicates that 10 percent of the sockeye recaptured entering the lake were wounded by seals and otters in the Ozette River, while up to an additional 50 percent of the fish marked downstream were not successfully recaptured entering the lake, suggesting that a significant but unquantified level of aquatic mammal predation occurs in the river, estuary, and nearshore environment. The level of impact to the population is thought to increase as the run size decreases. Natural and hatchery-origin sockeye produced in Lake Ozette tributaries can buffer the effects of predation on the beach spawning population by increasing the number of adult fish entering fresh water and potentially "swamping" predators.

The disposition of adult sockeye entering the lake and holding for several months prior to spawning is not fully understood. Assessing adult sockeye mortality rates during the holding period is complicated by the relatively large size of the lake, the small size of the population, sockeye holding behavior, and limnological conditions that limit direct observations of sockeye mortalities and the number of sockeye surviving to spawn in the lake. Limiting factors affecting sockeye holding in Lake Ozette include predation by aquatic mammals. The degree to which predation on holding adult sockeye limits sockeye survival is unknown and remains a data gap.

Beauchamp et al. (1995) suggested that cutthroat trout within Lake Ozette were consuming most of the fry produced within the watershed. Other factors, such as harvest and habitat degradation, may have reduced the sockeye population to levels such that predators could consume the majority of juveniles produced. It is possible, however, that increased sockeye fry recruitment to the lake from tributary production has decreased the rate of predation since Beauchamp's studies. Age-0 *O. nerka* population dynamics have likely changed dramatically since the early 1990s, commensurate with the advent of substantial fry production by the tributary hatchery program. Future studies should specifically monitor piscivorous fish predation of juvenile sockeye in the lake. Quinn (2005) found that average survival from fry-to-smolt for sockeye in other lake systems averages roughly 25 percent, and that predation is presumably responsible for most of the mortality in the sockeye lakes studied.

Smolt trapping and adult sockeye weir enumeration data indicate that large numbers of predators congregate in the Ozette River during the smolt emigration period. Stomach content analyses of northern pikeminnow collected in the Ozette River smolt trap indicates that they actively feed on sockeye and coho smolts. The impact from predation on the emigrating sockeye smolt population was rated as moderate at low smolt abundance and low at moderate and high smolt abundances.

Processes and inputs: Processes and inputs affecting predator-prey balance and predation efficiency have been altered from pre-European contact conditions. Processes and inputs affecting predator efficiency include LWD recruitment and removal, which resulted in reduced habitat complexity.

Activities affecting inputs/processes: Activities affecting, or that have affected, the predator-prey balance in the Ozette watershed include: introduction of non-native fish species; historical (1948-1977) directed fisheries that resulted in decreased sockeye abundance; selective habitat alterations that negatively affected sockeye habitat (resulting in reduced sockeye abundance) but had a negligible effect (or positive effect) on predators' key habitat; increases in local pinniped populations caused by a combination of disruption and alteration in the marine ecosystem resulting in the reduction in the number of apex predators (e.g., orcas) that feed on pinnipeds; abandonment of the Ozette Village and resulting loss of local pinniped hunting; and implementation of the Marine Mammal Protection Act.

4.2.2 Contributing Limiting Factors

Contributing limiting factors affecting all Lake Ozette sockeye population segments include water quality, Ozette River streamflow, Ozette River habitat conditions, marine survival, and estuary alterations.

4.2.2.1 Water Quality (H#2-WQ)

Hypothesis 2: High stream temperatures and low frequency, high intensity turbidity events reduce the fitness of sockeye salmon entering or exiting Lake Ozette and result in decreased survival and productivity.

Life stages affected: Adult migration, adult holding, and juvenile emigration.

Rationale: High stream temperatures and low frequency, high intensity turbidity events occur during the adult sockeye migration period. The physiological optimum temperature for sockeye salmon is in the range of 12-15ºC (Brett 1971). Temperatures approaching 24°C have been recorded in the Ozette River during the period when adult fish are leaving the ocean and transiting the river to Lake Ozette. During the 2004 adult migration, it was estimated that ~56 percent of adult sockeye entered the Ozette River when daily stream temperatures were >18°C and more than 16 percent entered when daily average stream temperature exceeded 21°C.

During the past 90 years, air temperatures during the adult sockeye migration period are estimated to have increased by 1-2ºC, based on climate data from a nearby monitoring station. Air temperature is arguably the most important meteorological variable affecting lake surface temperature, as it is causally involved in all heat exchange processes except the absorption of solar radiation and the emission of long-wave radiation from the lake surface (Kettle et al. 2004). Thus the increase in average air temperature probably indicates an increase in average lake temperature since historical times.

Collectively, poor water quality conditions, especially during the later part of the run, are cause for concern. Adult sockeye covered in silt and bleeding from the gills have been observed in the Ozette River following high turbidity and SSC events. The size and angularity of suspended sediment particles in lower Coal Creek samples may explain field observations of sockeye impacts caused by SSC. The disposition of adult sockeye exposed to such conditions and then entering the lake and holding for several months prior to spawning is unknown; assessment of population status and mortality rates during the holding period is complicated by the relatively large size of the lake, the small size of the population, sockeye holding behavior, and limnological conditions that limit direct observations. However, delayed pre-spawning mortality related to decreased fitness from elevated water temperatures and high SSC events in the Ozette River is likely to reduce the number of sockeye that survive to spawn.

High stream temperatures occur in the Ozette River during the sockeye smolt emigration period, but the majority of the smolts emigrate before stream temperatures reach >16°C. Based on average emigration timing, only a small fraction of sockeye smolts are likely to encounter temperatures exceeding 18°C. Low frequency, high intensity turbidity events resulting in moderate physiological stress are of greater concern. In April, when average Ozette River streamflow is still ~400 cfs, SS inputs from Coal Creek would normally be diluted by flow contributions from the Ozette River; however, even 50 percent dilution of the SSC would have a negligible effect on the predicted impacts on sockeye salmon at the concentration levels estimated to occur following a 2-inch precipitation event (see LFA).

From May to August when the lake level is typically low, no or very limited dilution from the Ozette River would be expected, because high intensity rainfall events usually reverse the flow of the Ozette River (during low lake level periods) and Ozette River flow is made up almost entirely of Coal Creek discharge. Severity indices estimated from data tables in Newcombe and Jensen (1996) indicate that for moderately common storm events in Coal Creek (10 percent to 3 percent probability of occurrence on any given day from May-August), moderate behavioral and physiological stress could occur for juvenile sockeye. Effects could include moderate physiological stress; moderate habitat degradation and impaired homing; and major indications of physiological stress and poor condition. During the month of May, no more than 7.5 percent of the average annual emigrating smolt population is expected to encounter suspended sediment at concentrations predicted to result in moderate physiological stress.

Processes and inputs: Processes and inputs affecting water quality in the Ozette River include: thermal inputs, hydrology, and sediment inputs.

Activities affecting inputs/processes: The following activities affect water quality conditions in the Ozette River:

- Large woody debris (LWD) removal or losses in LWD volume has caused channel destabilization, which, in turn, can result in higher turbidity and suspended sediment concentrations.
- Logging and road building have increased sediment inputs, reduced sediment storage, and resulted in more frequent high suspended sediment concentration events in the Ozette River.

- Channel alterations and sediment mobilizing events have increased coarse sediment deposition at the confluence of Coal Creek and the Ozette River. Increased sediment deposition has resulted in an increase in the lake's outlet control elevation, thereby altering the river's streamflow (see Hypothesis 3), which may result in reduced water quality.
- Increased carbon dioxide and other greenhouse gas emissions have altered and are altering the global climate, resulting in warmer lake and river temperatures.

4.2.2.2 Ozette River Streamflow (H#3-Q)

Hypothesis 3: Reduced streamflows in the Ozette River affect water quality and predation rates and efficiency and reduce the fitness of migrating and emigrating sockeye.

Life stages affected: Adult migration and juvenile emigration.

Rationale: Available discharge data for the Ozette River at the lake outlet indicate a clear trend of decreasing baseflow (summer discharge) over time from the 1970s to 2000s (Haggerty et al. 2007). The decrease is likely caused by multiple factors acting cumulatively over time.

Available data do not indicate that precipitation or lake level have changed dramatically over time to influence Ozette River discharge. Rather, internal mechanisms are at play. A significant change in the lake stage-streamflow relationship occurred in the Ozette River between 1979 and 2002, indicating that streamflow in the Ozette River is lower for a given lake stage in 2002 than it was in 1979. The percentage of hyporheic (underground) flow to total flow may have changed because of sedimentation near the confluence of the Ozette River and Coal Creek. Increasing shoreline vegetation has increased evapotranspiration, potentially influencing lake levels and thus river discharge. Summer base flows into Lake Ozette may have declined as a result of the effects of land use on fog drip, summer transpiration efficiency of dominant vegetation, soil water retention, and floodplain water storage. These hypothesized reductions in summer water inputs to Lake Ozette could translate to reduced Ozette River streamflow.

Reduced streamflow has the potential to affect water quality, predation rates and efficiency, and migration, reducing the fitness of migrating adult sockeye. For example, in return year (RY) 2003, just under 38 percent of the sockeye entered when streamflow was less than 100 cfs. Approximately 10 percent of the RY 2003 sockeye entered the lake when flows were less than 35 cfs. The lowest flow in which sockeye were observed migrating was 11 cfs. The overall decrease in baseflow (summer discharge) during the sockeye migration period remains unknown, and the relative contribution of the aforementioned factors is poorly understood, as are the biological effects.

Processes and inputs: Processes and inputs affecting streamflow in the Ozette River include: climate; lake and tributary hydrology; sediment input, routing, and storage in the upper half-mile of the Ozette River; and LWD recruitment and storage (in logjams) in the upper one mile of the Ozette River.

Activities affecting inputs/processes: Activities affecting Ozette River streamflow hydrology include:

- Historical LWD removal in the Ozette River
- ONP facilities operation and maintenance in Ozette River riparian zone
- Logging and road building throughout the watershed and specifically in Coal Creek
- Agriculture and rural development in the Big River valley
- Other floodplain alterations in major tributaries to the lake

4.2.2.3 Ozette River Habitat Conditions (H#4-Hab)

Hypothesis 4: Reduced pool depth, volume, and cover have decreased sockeye refuge areas and their ability to avoid predators, thus increasing predator efficiency.

Life stages affected: Adult migration and juvenile emigration.

Rationale: The loss of large (>50 cm diameter) woody debris (LWD) in the Ozette River through past removal operations has undoubtedly reduced habitat complexity throughout much, if not all, of the Ozette River. Past riparian forest removal adjacent to the upper 0.4 miles of the Ozette River has reduced LWD inputs, delaying the recovery and habitat potential of the upper river. Although adult sockeye spend a limited amount of time in the Ozette River, habitat simplification reduces refuge areas, making adult sockeye more susceptible to predation. Reduced LWD and habitat complexity also reduce refuge areas for emigrating juvenile sockeye. Sediment inputs from Coal Creek may degrade spawning habitat quality by increasing the levels of fine sediment in spawning gravels; however, sockeye have not been documented spawning in the Ozette River. Excessive sediment inputs can reduce pool volumes and reduce the quantity of high quality pool habitat available to both adult and juvenile sockeye.

Processes and inputs: Processes and inputs affecting Ozette River habitat conditions include:

- LWD recruitment
- Sediment inputs and routing
- Streamflow

Activities affecting inputs/processes: Activities affecting Ozette River habitat conditions include: historical LWD removal, historical riparian logging and clearing along the Ozette River, watershed-scale logging and road building (especially in Coal Creek), and, to a lesser degree, ONP riparian infrastructure and maintenance. Other activities identified that affect streamflow also affect habitat quality in the Ozette River (see Hypothesis 3).

4.2.2.4 Marine Survival (H#5-MS)

Hypothesis 5: Survival in the marine environment is driven by large-scale climatic processes, which are mostly not controllable. Variability in marine survival rates for sockeye salmon is significant, but not likely a key limiting factor at present. Large-scale changes in marine conditions should be monitored and may be significant in the future.

Life stages affected: Ocean rearing

Rationale: Mortality of large southern (< 55°N longitude) sockeye smolts in the marine environment averages 83 percent (Koenings et al. 1993). Mortality in the marine environment is likely the largest single mortality factor affecting juvenile and sub-adult sockeye. However, it is important to recognize that: 1) very high mortality rates in the marine environment are natural, and 2) there are no known direct actions that can be taken in the marine environment to improve survival for Ozette sockeye. While marine survival is a critical component in determining the ultimate abundance of Lake Ozette sockeye, broad-scale, regional studies of decadal scale productivity indicate that changes in marine survival played a limited role in the decline of Ozette sockeye (for additional details see LFA Sections 3.1.10, 4.1, 5.2, 5.6, 6.1.13, and 7.13) (Haggerty et al. 2007)

In the future, marine survival has the potential to limit the marine distribution of sockeye salmon and ultimately the viability of the species within the southern range. Welch et al. (1998) found that, “At the current rates of greenhouse gas emissions, predicted temperature increases under a doubled CO_2 climate are large enough to shift the position of the thermal limits [of sockeye salmon] into the Bering Sea by the middle of the next century [~2050]. Such an increase would potentially exclude sockeye salmon from the entire Pacific Ocean and severely restrict the overall area of the marine environment that would support growth.”

Processes and inputs: Processes and inputs affecting marine survival include climate, natural patterns and variations in upwelling and ocean productivity, and marine predator-prey balances.

Activities affecting inputs/processes: Global and broad-scale regional degradation of the marine environment caused by pollution, fisheries, and climate change is likely to adversely affect future marine survival rates and marine distribution of all Northeast Pacific-origin sockeye salmon populations.

4.2.2.5 Estuary Alterations

Changes in the tidal prism and estuarine habitat conditions appear to have occurred during the last 50 years. The cause of these apparent changes is poorly understood, as are the potential effects on Lake Ozette sockeye. Changes in the estuarine habitat conditions have an unknown impact on sockeye smolt and adult survival. This potential limiting factor remains a data gap, but it may be a contributing limiting factor because changes in the estuary can affect predator-prey interactions, water depths and estuary/ocean accessibility, estuary nutrient supply, and salinity gradients and osmoregulation. Marine survival data for Ozette are limited but suggest that mortalities occurring in the estuary-ocean entry phase are within the limits experienced by other sockeye salmon smolts within the southern range of the species.

4.2.3 Factors Not Likely Limiting Sockeye

The following factors were evaluated and determined not likely to limit sockeye salmon VSP parameters.

4.2.3.1 Ocean Fisheries

Section 6.1.13 in the LFA reviews the major Alaska, British Columbia, and Washington marine area fisheries that harvest sockeye salmon migrating in Northeast Pacific Ocean areas. The review presented in the LFA indicates that fisheries directly and incidentally affecting sockeye salmon in the ocean are not likely to be substantial risk factors to Ozette sockeye salmon survival and recovery to a viable status. The review of ocean fisheries effects on Ozette sockeye presented in LFA Section 6.1.13 is summarized below.

Commercial net and troll fisheries extending from Dixon Entrance in southeast Alaska to the Strait of Juan de Fuca were reviewed for the timing and duration of fishery openings relative to the estimated migration time of Ozette sockeye through harvest areas. The evaluation of these ocean fisheries in the LFA concludes that there are no directed commercial sockeye fisheries in the marine environment when and where the Ozette sockeye population is present during the ocean rearing and migration period. The early-return timing of Ozette sockeye (May through late June entry into freshwater) substantially limits their presence in marine migratory areas when and where commercial and sport fisheries directed at other Washington and British Columbia-origin sockeye populations occur. The only ocean fishery for sockeye reviewed in the LFA that occurs when the later portion of the Ozette sockeye return may be present is a single boat test gillnet fishery on the southwest coast of Vancouver Island. The test fishery commences during the third week of June each year (near the end of the Ozette sockeye migration period into the Ozette River), and is conducted to assess Fraser River sockeye run size abundance. Sockeye racial identification data collected through the test fishery indicate that one Ozette sockeye may have been encountered during test fishing several years ago. All other sockeye that have been captured in the fishery originated from the Fraser River, with some contribution of Lake Washington fish. Harvest impacts on Ozette sockeye from directed sockeye salmon fisheries in the ocean are not risk factors limiting population recovery.

There is a potential for incidental harvest of Ozette sockeye resulting from interceptions in ocean sport, commercial, and tribal fisheries directed at other salmon species and groundfish. However, mortality of Ozette sockeye from such fisheries is likely to be extremely low. Review of Washington State and tribal catch information for Washington ocean Chinook and coho salmon and groundfish fisheries that occur during the Ozette sockeye migration period indicates that the fisheries rarely encounter sockeye salmon. Incidental harvest resulting from other salmon fisheries, or from groundfish fisheries, is not a substantial factor affecting Lake Ozette sockeye salmon recovery. There is also no evidence that high seas flying squid fisheries are currently adversely affecting Lake Ozette sockeye salmon and other Northeast Pacific salmon stocks. Illegal squid fishing in the past may have affected abundances of salmon returning to Washington waters; however, increased enforcement of fishing boundaries by the US Coast Guard and enactment of bans on the sale of salmon captured in squid fisheries by Japan and Korea appear to have substantially diminished salmon bycatch in squid fisheries.

4.2.3.2 Freshwater Fisheries

4.2.3.2.1 Ozette River Fisheries

The Ozette River is closed to all sport fishing until August 1. Very few sockeye are still in the river after August 1. When the river is open, selective fishery rules apply and all sockeye must immediately be released. There are no likely impacts from permitted fisheries during the adult migration or juvenile emigration periods. No tribal salmon fisheries are conducted within the watershed. Some poaching may occur, but no actual incidents of poaching have been documented by the NPS. Dense riparian undergrowth makes it difficult to reach the river, and park rangers are present at the access points at the river mouth and upper river.

4.2.3.2.2 Lake Ozette Fisheries

Under National Park Service regulations, the lake is open to catch and release salmonid fishing, but the fish must be immediately released. The smolt emigration period begins before the annual sport fishery opens, and the majority of sockeye smolts are in the lake during the first few weeks of the fishery. However, fingerling (age 0) sockeye are unlikely to be susceptible to fishing because of their small size. There are no empirical data regarding fishing pressure (e.g., angler days) or targeted or untargeted sockeye encounters within the lake. However, field observations indicate that Lake Ozette has low fishing pressure, which further reduces the potential impact of incidental sockeye encounters. Fisheries impacts on sockeye in the lake are unlikely. These conclusions are consistent with information provided by members of the Limiting Factors Rating Workgroup who have direct experience and knowledge regarding Lake Ozette sport fisheries.

4.2.3.3 Research and Monitoring

No direct adult sockeye mortalities at the weir in the Ozette River caused by physical injury from weir and smolt trapping equipment have been documented. However, adult sockeye migrating into the lake are especially susceptible to predators as they transit the weir. The weir acts as a bottleneck for migrating adult sockeye, and harbor seals and river otters appear to use the weir as a hunting aid. Seals and otters have frequently been observed working the face of the weir, swimming back and forth across the river in search of sockeye. It appears that the susceptibility of adult sockeye to predation at the weir increases as lake level declines. The counting weir may also delay migrants from entering the lake and increase their exposure time to elevated stream temperatures and/or high SSC. Since 1998, weir operations have been conducted with the weir left open 24 hours a day to allow free fish passage into the lake in order to minimize impacts of high water temperatures and potentially enhanced predation efficiency associated with the weir (for a complete description of weir operations see the LFA). Smolt trapping data indicate that very few direct mortalities result from smolt trapping (<1 percent of all smolts encountered). The indirect effects of smolt trapping are discussed in Hypothesis 1 above.

4.2.3.4 Disease

Sockeye health in the river is not systematically monitored. Observations of infections and fungus growth are occasionally included in weir observation notes, but no systematic inventory data are collected. The disposition of adult sockeye entering the lake and holding for several months prior to spawning is not fully known. During RY 2000, 899 sockeye were trapped and visually examined for external tags and physical condition. Less than 1 percent of the sockeye transiting the weir had visible fungal growth. However, at least some individual sockeye have been observed with severe external infections, and these fish likely die before reaching the spawning grounds. Assessment of population status and mortality rates during the holding period is complicated by the relatively large size of the lake, the small size of the population, sockeye holding behavior, and limnological conditions that limit direct observations of sockeye mortalities and the number of sockeye surviving to spawn in the lake. The degree that disease limits sockeye salmon survival during holding is thought to be minimal, based upon observations of external conditions of sockeye entering the lake. However, more data are needed. It is possible that high water temperatures or other factors (i.e. predator wounds, gill abrasion) increase susceptibility to disease.

4.2.3.5 Hatchery Practices

Hatchery practices implemented as part of the Lake Ozette HGMP include measures to minimize potential disease and genetic impacts on all spawning aggregations. Annual sockeye salmon egg take and fry production levels are maintained at conservative levels to ensure that fry are not overproduced. Unlimited hatchery production of fry could result in cropping and depletion of zooplankton species important for sockeye growth and survival during the lake rearing period. Ozette hatchery practices are appropriately limited in scope and scale, minimizing the risks of adverse hatchery impacts on natural-origin juvenile sockeye rearing in the lake.

4.3 LIMITING FACTORS AFFECTING BEACH SPAWNERS

The Lake Ozette Sockeye LFA identified and characterized limiting factors by life stage and degree of impact of each limiting factor within each life stage for Lake Ozette beach spawning sockeye. As detailed in Section 4.2, all Lake Ozette sockeye experience similar conditions while holding and rearing in the lake and migrating to or from the ocean via the Ozette River. Beach spawning sockeye experience habitat conditions and limiting factors different from those affecting tributary spawners during four life history stages: adult staging, beach spawning, egg incubation, and emergence and dispersal. The results of the LFA for all beach spawning subpopulations are included below in Figure 4.5. Each limiting factor was assessed based upon the life stage affected, the process or input influencing the limiting factor, and activities that affect each process and input. A summary of this assessment is included in Figure 4.6. A detailed narrative of key and contributing limiting factors is included in Sections 4.3.1 and 4.3.2.

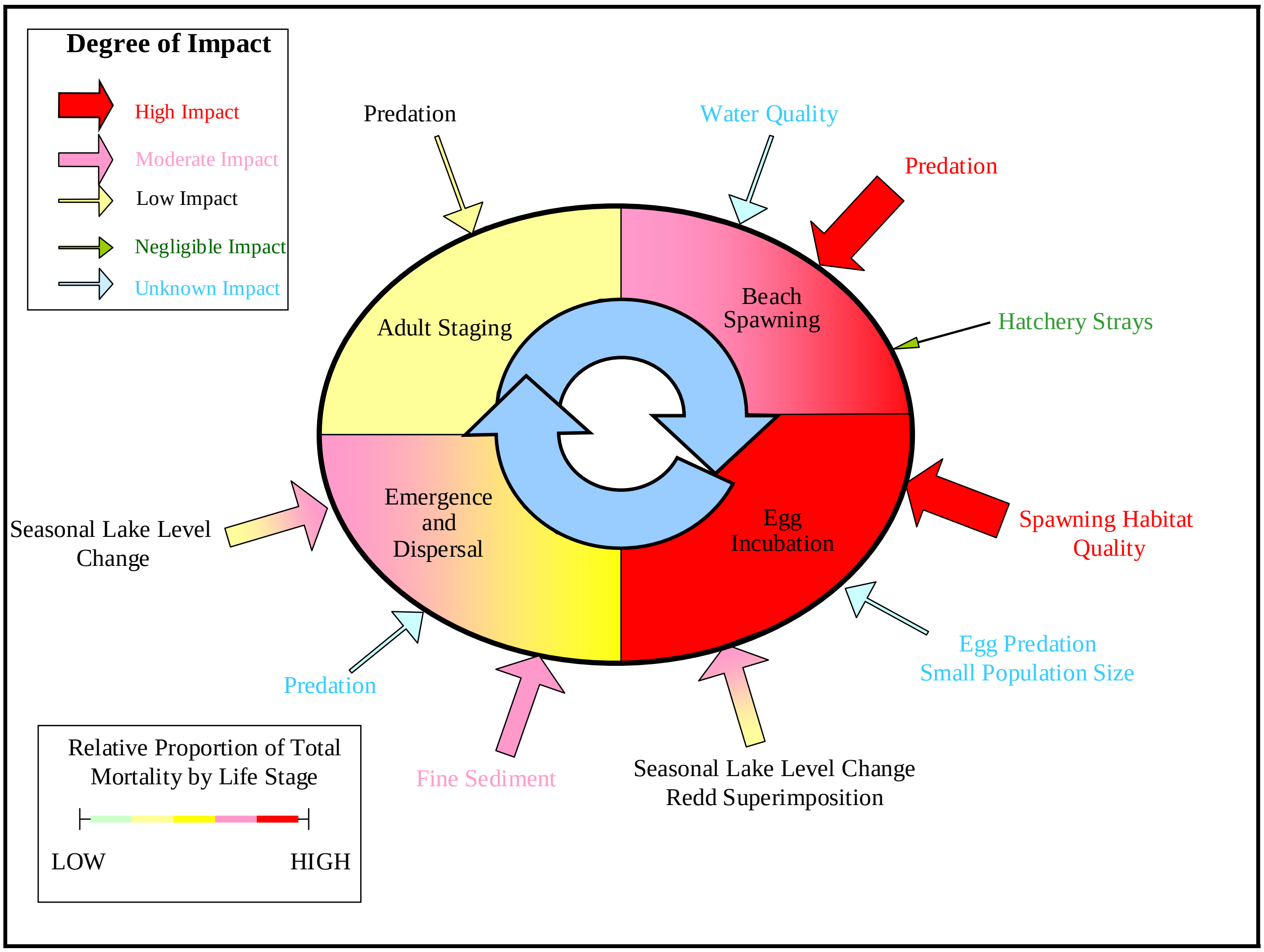

Figure 4.5. Conceptualization of hypothesized limiting factors affecting beach spawning Lake Ozette sockeye subpopulations. Arrows depict the degree of impact for each

limiting factor and colored polygons depict the relative proportion of total mortality by life stage.

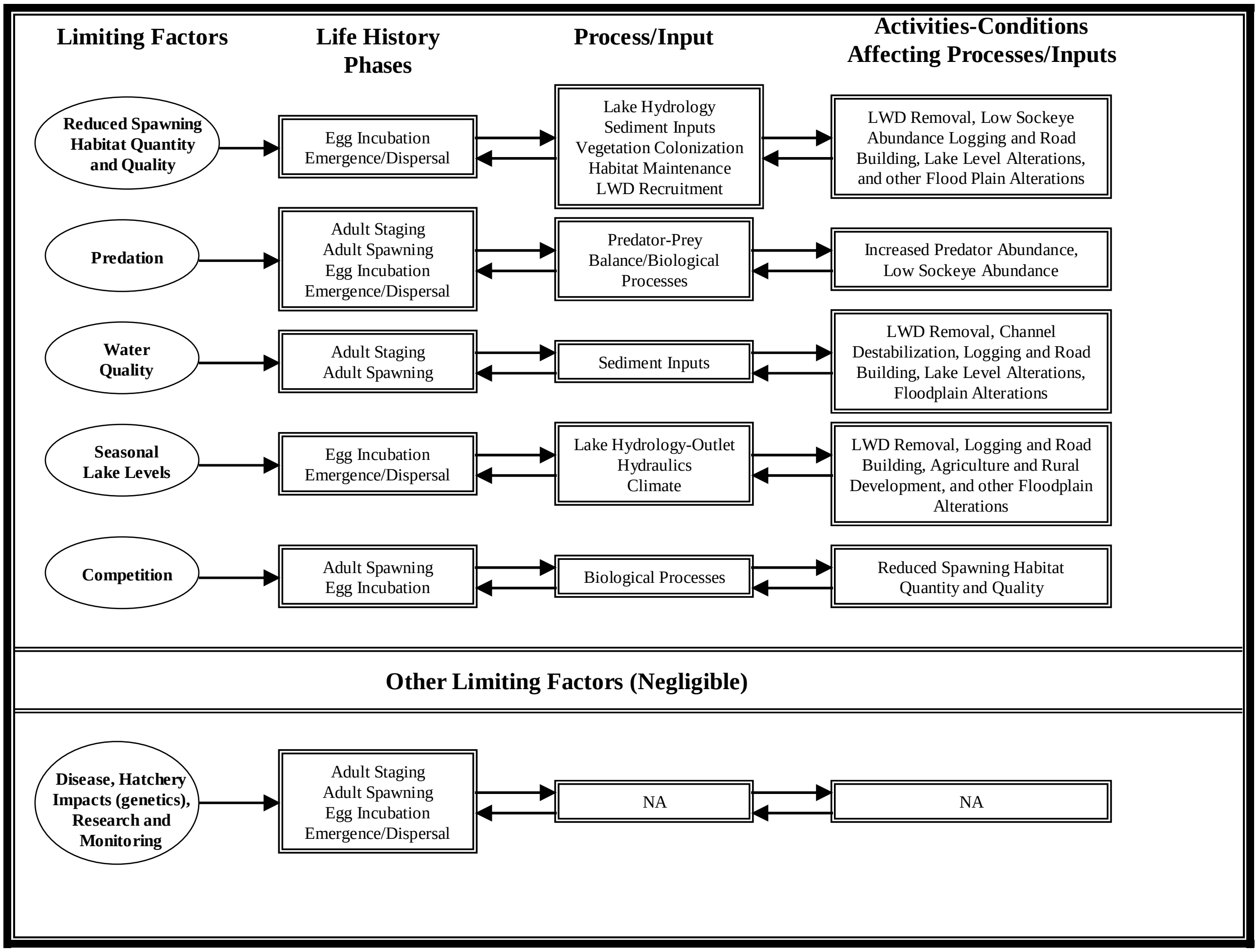

Figure 4.6. Hypothesized limiting factors affecting only beach spawning subpopulations, life history phases affected, processes and inputs regulating limiting factors, and activities/conditions affecting processes and inputs.

4.3.1 Key Limiting Factors

Key limiting factors affecting beach spawners are reduced quantity and quality of spawning habitat and predation.

4.3.1.1 Reduced Quantity and Quality of Spawning Habitat (H#6-BSH)

Hypothesis 6: Reduced quality and quantity of beach spawning habitat in Lake Ozette has decreased egg-to-emergence survival, resulting in reduced fry production from the beach spawning aggregations.

Life stages affected: Egg incubation and emergence/dispersal.

Rationale: The quality and quantity of beach spawning habitat varies by spawning beach and site within each of the extant (and historically existent) spawning beaches. The results of egg incubation studies on Olsen's Beach strongly suggest that egg survival after deposition is extremely poor (<<10 percent) within most of the primary spawning area. Not all egg mortality in the studies could be explained by fine sediment concentrations alone. Several environmental variables are likely at work collectively reducing egg survival. Sockeye salmon egg-to-fry survival on Lake Ozette beaches is limited by lack of adequate oxygen exchange from incubation water to the eggs, caused independently by two primary factors and their synergistic interactions: 1) reduced intergravel flows, and 2) high levels of fine sediment (i.e. < 0.85mm). Fine sediment levels and intergravel flows are partially controlled by lake level, wave energy, tributary sediment inputs, vegetation, seasonal groundwater levels, and other mechanisms. The synergistic effects of multiple variables (inputs/processes/actions) that interact to limit egg-to-emergence survival make it extremely difficult to link each specific process or input to a specific level of impact. Cumulatively, incubation conditions (lake level, fine sediment, vegetation, intra-gravel flow, etc.) on the spawning beaches are poor and the impact on sockeye productivity and survival was therefore rated high (LFA, Haggerty et al. 2007), making this a key limiting factor.

Fine Sediment. Fine sediment levels exceed 25 percent (dry method; wet sieve equivalent ~37 percent) on the remaining spawning beaches. Fine sediment levels exceed 50 percent at Umbrella Beach (from Herrera 2006). Excessive sediment production in tributaries (from a combination of land use, LWD removal, and base level incision) and subsequent delivery to spawning beaches has decreased the quantity and quality of spawning habitat available. The total quantity of spawning habitat eliminated as a result of increased fine sediment deposition altering substrate size and character is unknown, but at least one entire historically used spawning beach has been lost (Umbrella Beach). Egg incubation studies conducted in 2000 and 2001 found that fine sediment deposition on redds located at the two known sockeye spawning beaches occurred during the egg incubation period. Fine sediment deposition during incubation can form an impenetrable layer of fine sediment, impeding emergence. *In situ* studies demonstrating poor survival from eyed egg to pre-emergence indicate that the majority of mortality occurs prior to emergence.

<u>Shoreline Vegetation</u>. Quantification of potential lost spawning habitat resulting from lake level alterations is presented in detail in the LFA. A major change visible in photographs between 1953 and 2003 is the increase of vegetation around the lake's shoreline – a 56 percent net *decrease* in the quantity of *un*vegetated shoreline. Much of the increased vegetation along the shoreline has been attributed to lower average lake levels (or lower growing season lake levels) and increased fine sediment. In addition, it has been hypothesized that alterations in lake level variability from removal of wood at the lake outlet and tributary-inflow hydrologic change, coupled with tributary

sedimentation and wood removal, have altered hyporheic and groundwater hydraulics, hydrology, and inter-gravel flow along the lake shoreline.

Historically, LWD was also removed from portions of the lake shoreline. This removal affected the shoreline hydraulics, resulting in reduced localized turbulence around wood. Shoreline wood functions to cleanse gravel locally and scour colonizing vegetation through turbulence. Without wood, vegetation can more effectively colonize bare soil and trap fine sediment, reducing substrate size and habitat suitability.

Lake Level. As described in Section 2.4, seasonal lake level changes are known to directly result in sockeye redd dewatering. Further, through modeling studies using the available data, Herrera (2005, 2006) found it likely that mean lake level during the beach sockeye spawning period has been lowered by 1.5 to 3.3 feet from historical levels.

Processes and inputs: Processes and inputs affecting the quantity and quality of beach spawning habitat in Lake Ozette include: lake hydrology, sediment inputs, vegetation colonization, LWD recruitment, and habitat maintenance.

Activities affecting inputs/processes: Activities affecting the quantity and quality of beach spawning habitat include:

- Historical tributary and lake outlet LWD removal and resulting channel destabilization and altered lake levels.
- LWD removal from beaches.
- Past and present land use activities (logging, road building, agriculture and rural development) that result in changes to water quantity and quality and sediment production.
- Sockeye fisheries and other activities that directly or indirectly reduce sockeye abundance may also contribute to the degradation of spawning habitat by reducing the ability of sockeye salmon to maintain productive habitat through gravel cleaning and coarsening during the act of spawning.

4.3.1.2 Predation (H#7-Pred)

Hypothesis 7: Changes in relative predator-prey abundances on Ozette spawning beaches have increased the proportion of adult sockeye, eggs, and newly emerged fry consumed by predators, resulting in decreased freshwater survival.

Life stages affected: Adult staging, adult spawning, egg incubation, and emergence and dispersal.

Rationale: Indirect observational data suggest that sockeye salmon are much less vulnerable to predation during the pre-spawning staging period because the fish hold off-shore, in deeper water, and at lower densities, making them less susceptible to predation. However, no direct estimates of predation-related mortality during the sockeye staging period have been made. High impacts on sockeye are attributed to predation on the spawning grounds. Data collected during the spawning season in 2000 suggest that 40 percent or more of the sockeye at Allen's Beach were killed by harbor seals and river otters before completing spawning. Data from Olsen's Beach during the same year indicates that approximately 10 percent of the spawners were killed by seals and otters. Both predatory mammal species have been observed foraging at known beach spawning areas during the sockeye spawning period. Continued monitoring is needed to fully document the degree of predation occurring, but the limited data collected to date indicates the potential for substantial predation on the spawning grounds.

Egg predation occurs at unknown levels on the spawning beaches. Known predators of viable sockeye eggs at Lake Ozette include sculpins and aquatic insects. Currently there is no evidence that suggests that egg predation has increased relative to historical baseline levels. However, at low spawning escapement levels egg predation could play an important role in limiting population growth because of potential depensatory effects.

The level of impact of predation occurring at the sockeye fry emergence life stage is unknown. A number of species of aquatic predators exist throughout the littoral zone. Directly upon emergence, sockeye fry are vulnerable to non-native piscivorous species such as largemouth bass and yellow perch, as well as native piscivorous species (e.g. cutthroat trout). Small numbers of beach spawners and poor egg-to-fry survival can make juvenile sockeye vulnerable to the depensatory effects of predation at reduced abundance. Predator interactions at this early life history stage remain a data gap, but it is possible that significant levels of predation occur in the vicinity of the spawning beaches.

Processes and inputs: Processes and inputs affecting predator-prey balance have been altered from pre-European contact conditions.

Activities affecting inputs/processes: Activities affecting or that have affected the predator-prey balance in the Ozette watershed include: introduction of non-native fish species; past directed Ozette sockeye fisheries that resulted in decreased sockeye abundance; selective habitat alterations that negatively affected sockeye habitat (resulting in reduced sockeye abundance) but had a negligible effect (or positive effect) on predator's key habitat; increases in local pinniped populations caused by a combination of disruption and alteration in the marine ecosystem resulting in a reduction in the number of apex predators (e.g., orcas) that feed on pinnipeds; abandonment of the Ozette Village and resulting loss of local pinniped hunting; and implementation of the Marine Mammal Protection Act and other regulations that limit removal of predators and promote their increase while failing to recognize the effects of the regulations on the abundance of sockeye salmon (e.g., ONP fishing regulations, hunting and trapping restrictions inside and outside the boundaries of ONP).

4.3.2 Contributing Limiting Factors

Contributing limiting factors affecting beach spawners are water quality, seasonal lake level changes, and competition.

4.3.2.1 Water Quality (H#8-WQ)

Hypothesis 8: Turbidity and suspended sediment concentration at Olsen's and Allen's Beaches have a limited effect on sockeye salmon because of the substantial distance of these beach spawning areas from major sediment sources. However, at historical spawning sites near major tributary outfalls, such as Umbrella Beach, the effects of turbidity and SSC would be expected to be similar to those described in Hypothesis 13.

Life stages affected: Adult staging, adult spawning, egg incubation, and emergence and dispersal.

Rationale: The effects of water quality on sockeye salmon during the staging period are unknown and remain a data gap. However, limited water quality data collected in the offshore environment suggest that conditions there are favorable for sockeye and that water quality is not likely a significant limiting factor during this life history stage. Sockeye are exposed to less optimal water quality conditions closer to the shoreline and near tributary outfalls.

High turbidity and SSC levels in tributaries to the lake can result in high turbidity levels along the lake shoreline. The frequency of high turbidity events and the direct effect on spawning sockeye are unknown but may include moderate physiological stress, habitat avoidance, and spawning habitat degradation. Turbidity and SSC data are lacking on the extant spawning beaches and are considered an important data gap. In general, existing beach spawning habitats, especially Allen's Beach, are less susceptible to stream derived turbidity and SSC because of their distance from major sediment sources in eastern tributaries. However, at historical beach spawning sites, such as Umbrella Beach, turbidity impacts are expected to be similar to those in Umbrella Creek.

Processes and inputs: Processes and inputs affecting Lake Ozette water quality include sediment inputs and routing.

Activities affecting inputs/processes: Activities affecting Lake Ozette water quality include LWD removal and channel destabilization, logging and road building, and floodplain alterations.

4.3.2.2 Seasonal Lake Level Changes (H#9-LL)

Hypothesis 9: Seasonal lake level changes result in redd dewatering, decreasing egg-to-fry survival rates.

Life stages affected: Egg incubation and emergence and dispersal.

Rationale: The impact of lake level changes varies depending upon redd elevations relative to water surface elevation at emergence. Detailed redd mapping on Olsen's Beach during the winter of 2000/01 indicated that approximately 3 percent of the total redd surface area (7 total redds) was completely dewatered at the time of emergence. Spawning surveys conducted between 1999 and 2004 did not indicate high amounts of redd dewatering. However, high lake levels early in the spawning season followed by drought conditions would likely result in moderate amounts of dewatered redds if the winter lake level goes below 33 ft (MSL- NGVD 1929). Additional monitoring of redd dewatering is needed.

Beyond natural climate variability, cumulative land use activities have likely altered seasonal lake level changes away from the natural state. Historical wood removal from the Ozette River has altered the hydraulic efficiency of the lake outlet and changed the backwater influence of river wood on lake stage. The increased efficiency of outlet drainage has increased rates of change in lake stage (e.g., how quickly the lake level falls) and reduced the average lake level and absolute low lake stages (see LFA and Herrera 2005). However, recent sedimentation of Ozette River near Coal Creek has partially offset (by ~1 foot) these reduced low lake levels, through control on water discharge into Ozette River, especially during summer months. The combination of these altered hydraulic factors, in addition to lake inflow hydrology, needs to be researched further to determine the exact consequences of anthropogenic lake level changes on sockeye redd dewatering on the beaches.

Lack of long-term hydrologic data sets in Ozette tributaries prohibits the exact quantification of any potential changes to tributary hydrology and flow regimes from land use and channel modifications. The high road densities in sockeye tributaries (averaging >6.0 mi/mi^2), extensive clear-cutting (>95 percent of sockeye watersheds clear-cut at least once), and lack of floodplain connectivity (because of channelization and wood removal) cumulatively lead to the hypothesis that hydrologic change has occurred in Ozette tributaries, but with an unknown magnitude. This is consistent with the voluminous literature showing that water yield changes begin following a significant (10 to 25 percent) reduction of forest vegetation cover, with the highest impacts in conifer forests in high precipitation zones. However, quantification of this potential limiting factor locally remains a data gap.

Processes and inputs: Processes and inputs affecting Lake Ozette seasonal lake level changes include lake outlet hydraulics (Ozette River), tributary watershed hydrology, and climate variability.

Activities affecting inputs/processes: Activities affecting seasonal lake level changes beyond natural climate variability are those that affect watershed hydrology and lake hydro-period, i.e., historical LWD removal from the Ozette River, sedimentation in the Ozette River, current and past logging and road building, agriculture, and floodplain alterations.

4.3.2.3 Competition (H#10-Comp)

Hypothesis 10: Reduced spawning habitat quality and quantity have increased the competition for suitable habitat at low to moderate spawning escapement levels, resulting in increased redd superimposition and decreased egg-to-fry survival.

Life stages affected: Adult spawning and egg incubation.

Rationale: The LFA rated the impact of competition as moderate for the Olsen's Beach core spawning area and low for all other beach spawning sites. Redd superimposition on the spawning beaches is thought to significantly reduce the survival of previously deposited eggs. The degree to which this occurs is difficult to measure, but Olsen's Beach seems to be especially prone to multiple sockeye spawning events in the same location. During the 2000 sockeye spawning season, sockeye were observed spawning in the same location over an 89-day period. More than 90 percent of the redd surface area measured had been spawned in multiple times during the spawning season. These observations provide additional evidence that suitable/preferred spawning area is limited.

Processes and inputs: Competition for suitable spawning habitat at low to moderate spawner abundance is directly linked to reduced habitat quality and quantity. The processes that have reduced habitat quantity are the same processes responsible for increased competition. Since Ozette sockeye appear to prefer areas with springs and seeps for spawning, it is thought that alterations to the location, degree, and depth of upwelling could negatively affect beach spawning, although no such alterations have been documented.

Activities affecting inputs/processes: See Hypothesis 6 (reduced quantity and quality of beach spawning habitat).

4.3.3 Factors Not Likely Limiting Sockeye

The following factors were evaluated and determined not likely to limit sockeye salmon VSP parameters. A brief narrative is included summarizing why each factor is not likely to limit sockeye salmon population viability.

4.3.3.1 Research and Monitoring

Spawning ground surveys are conducted approximately every 7 to 10 days within the primary sockeye spawning areas. Spawning ground surveys are conducted by boat, snorkel, and/or SCUBA survey techniques. Surveyors are trained to identify and record all types of spawning activity, even under difficult or cryptic situations. Surveyors are also trained to avoid disturbing areas suitable for spawning and minimize disturbance to the lake bottom. Most redds remain visible during the entire spawning season, making avoidance of these areas especially easy for trained surveyors. It is highly unlikely that beach spawning ground surveys have any substantial direct effects on spawning sockeye.

4.3.3.2 Hatchery Impacts (Genetics)

Hatchery practices implemented through the HGMP include measures to minimize potential disease and genetic impacts on beach spawning aggregations. Imprinting juvenile sockeye by using on-station rearing in release watersheds reduces the risk of hatchery-origin sockeye straying onto beaches. Mark and recapture data collected at Olsen's and Allen's beaches indicates that few if any Umbrella Creek Hatchery releases return to spawn on Lake Ozette beaches. Approximately 25 percent of the brood year 1995 Umbrella Creek fed fry released were adipose fin clipped and in 1999 (at the time of their return), 121 adult sockeye salmon were sampled on Olsen's Beach and none were adipose fin clipped. This suggests that straying from tributary releases onto spawning beaches was nonexistent or at least very low (MFM 2000). Spawning adults returning from hatchery releases after 1999 were mass marked using thermal otolith marks (100 percent marking), as well as fin clips (45 percent of all fry and fingerlings released since BY 1999 have been fin clipped), allowing for monitoring of hatchery-origin fish distribution throughout the watershed. The results from otolith sampling are not yet available. Also, note that sockeye straying onto Olsen's Beach are likely to have a limited genetic impact if successful spawning occurs, since Olsen's and Umbrella Creek sockeye share common genetics (Hawkins 2004).

4.3.3.3 Disease

See Section 4.2.3.4

4.4 LIMITING FACTORS AFFECTING TRIBUTARY SPAWNERS

All Lake Ozette tributary spawning sockeye experience similar habitat conditions and limiting factors during four life history stages: tributary migration and holding, spawning, egg incubation, and emergence and dispersal. The Lake Ozette Sockeye LFA identified and characterized limiting factors specifically affecting the tributary subpopulations by life stage and degree of impact of each limiting factor within each life stage. The results of the LFA for all tributary spawning subpopulations are illustrated below in Figure 4.7. Each limiting factor was assessed based upon the sockeye life stage affected, the process or input influencing the limiting factor, and activities that affect each process and input. A summary of this assessment is presented in Figure 4.8. A detailed narrative of key and contributing limiting factors is included in Sections 4.4.1 and 4.4.2.

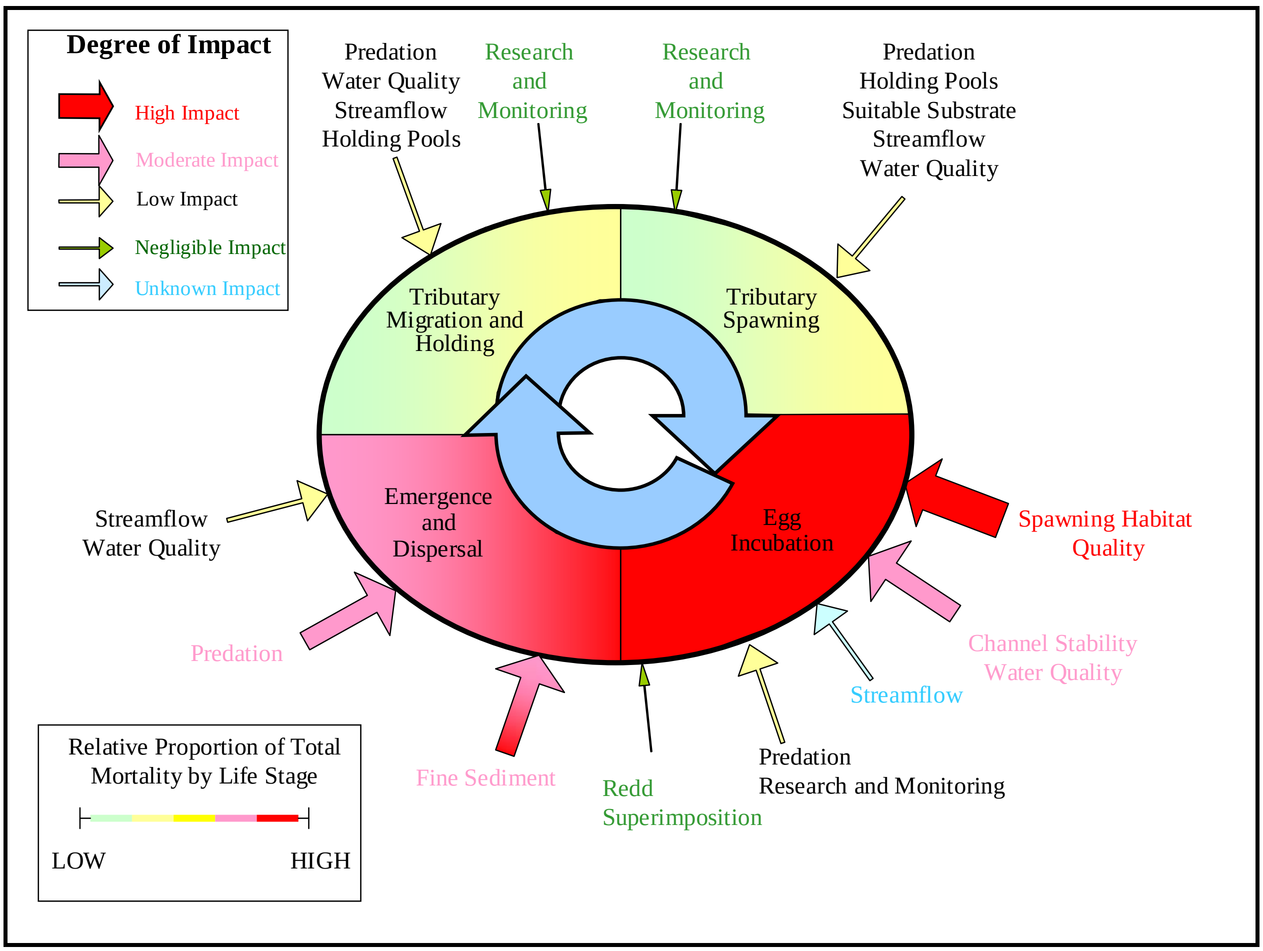

Figure 4.7. Conceptualization of hypothesized limiting factors affecting tributary spawning Lake Ozette sockeye subpopulations. Arrows depict the degree of impact for each limiting factor and colored polygons depict the relative proportion of total mortality by life stage.

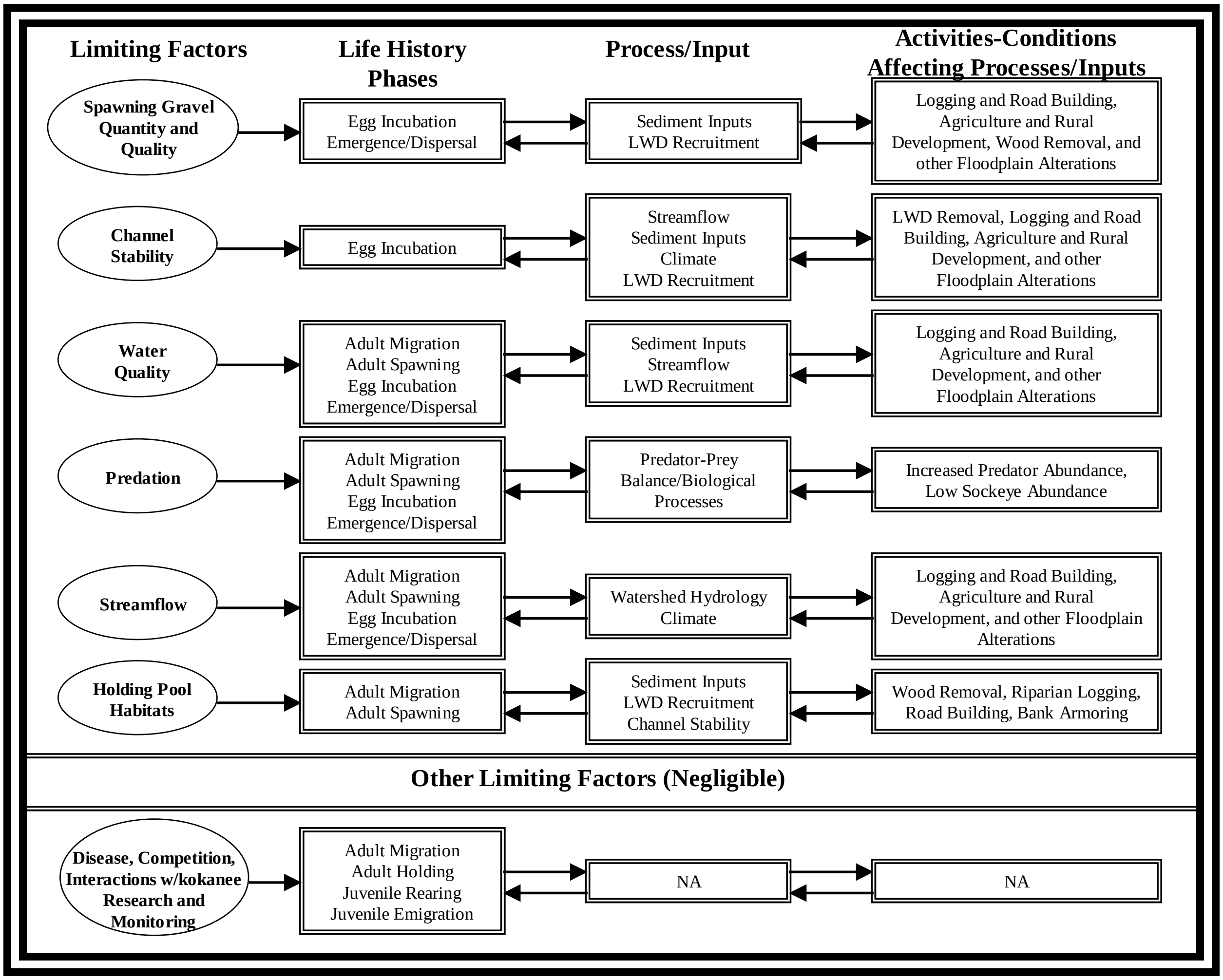

Figure 4.8. Hypothesized limiting factors affecting only tributary spawning subpopulations, life history phases affected, processes and inputs regulating limiting factors, and activities/conditions affecting processes and inputs.

4.4.1 Key Limiting Factor

The key limiting factor affecting tributary spawners is spawning gravel quantity and quality.

4.4.1.1 Spawning Gravel Quantity and Quality (H#11-TSH)

Hypothesis 11: Channel simplification and increased sediment production and delivery to streams have decreased the quantity of suitable spawning habitat (i.e., gravel) available to tributary spawning sockeye. Increased levels of fine sediment (<0.85mm) in spawning gravels reduces intra-gravel flow and oxygenation of redds, resulting in decreased egg-to-fry survival.

Life stages affected: Egg incubation and emergence/dispersal.

Rationale: Gravel storage behind large woody debris has been systematically reduced from historical levels throughout sockeye spawning tributaries. This has been coupled with increased fine sediment delivery to mainstem spawning reaches, together altering the distribution and availability of suitable spawning gravel. Some mainstem sections (e.g., lower Big River) have been entirely transformed from gravel bed to sand bed (see Kramer's [1953] substrate description). At the watershed scale, gravel quantity is still high, but with reduced quality and stability. Currently the effect of reduced gravel quantity on tributary spawning sockeye is low, but as the population increases the effects of lost habitat will result in increased competition for suitable spawning areas and reduced freshwater productivity.

High levels of fine sediment have been documented in sediment core sample data from spawning gravels in Lake Ozette tributaries. During incubation, salmonid eggs require sufficient water flow to supply egg pockets with oxygen and carry away waste products (Bjornn and Reiser 1991). Water circulation through salmon redds is a function of redd porosity, permeability, and hydraulic gradient (Bjornn and Reiser 1991). Fine sediment that settles into redds during the egg incubation period can impede water circulation and fry movement, which can result in decreased egg-to-emergence survival (Bjornn and Reiser 1991). Studies throughout the Pacific Northwest have found that increased levels of fine sediment (<0.85mm) in spawning gravels decreases egg-to-emergence survival (Cederholm et al. 1981; Bjornn and Reiser 1991; McHenry et al. 1994). McHenry et al. (1994) found that coho and steelhead egg-to-alevin survival decreased drastically when fine sediment (<0.85mm) exceeded 13 percent (volumetric method) in Olympic Peninsula streams. Numerous other researchers have also found that survival to emergence relates negatively to the percentage of fines in gravel (McNeil and Ahnell 1964; Koski 1966; Cederholm et al. 1981; Cederholm et al. 1982; Tappel and Bjornn 1983; Tagart 1984; Chapman 1988).

The high density of often poorly constructed, surfaced, and maintained roads, along with extensive, frequent timber clear-cutting in most subbasins from the 1950s to present, has resulted in increased sediment production and delivery to tributaries. Additionally, mass wasting, channel and bed destabilization, wood removal, decreased bank stability, and channel incision have increased sediment production and delivery to the stream network within the primary sockeye spawning tributaries. The exact degree that each input specifically increases or alters fine sediment levels in spawning gravel remains unknown. Duplicating sediment sampling conducted by McHenry et al. (1994) could help answer important questions regarding current and past fine sediment levels, as well as aid in predicting actions and timeframes required for gravel quality to reach desired conditions for adequate fry production.

Processes and inputs: Sediment inputs and routing and LWD recruitment.

Activities affecting inputs/processes: Past and present logging and road building, agriculture, rural development, floodplain alterations, bank armoring, and historical wood removal.

4.4.2 Contributing Limiting Factors

The contributing limiting factors affecting tributary spawners are channel stability, water quality, predation, streamflow, and holding pool habitat.

4.4.2.1 Channel Stability (H#12-Stab)

Hypothesis 12: Decreased channel stability and floodplain alterations have reduced egg-to-fry emergence survival in sockeye tributaries.

Life stages affected: Egg incubation and emergence/dispersal.

Rationale: The bed and banks of sockeye spawning tributaries have been destabilized by land use and stream management practices over the last 100 years. Channel destabilization and/or morphologic changes in channel form can result in lowered egg-to-fry survival during the egg incubation period. The degree that channel changes in Ozette sockeye tributaries have lowered egg-to-fry survival remains unquantified. Sediment transport and scour depth data have not been systematically collected along with fine sediment data at representative sockeye spawning locations. These data gaps need to be filled in order to assess the impact of wood removal, base level changes, incision, channelization, watershed sediment delivery, movement of sediment pulses, and streamflow magnitude on egg-to-fry survival. For a complete discussion on channel stability see the LFA.

Processes and inputs: Streamflow, climate, LWD recruitment, and sediment inputs.

Activities affecting inputs/processes: Past and present logging and road building, floodplain alterations (including agriculture, rural development, bank armoring), and historical wood removal.

4.4.2.2 Water Quality (H#13-WQ)

Hypothesis 13: Elevated turbidity and suspended sediment concentrations increase stress and reduce adult sockeye fitness, resulting in increased egg retention rates and pre-spawning mortalities. High levels of turbidity and SSC result in fine sediment deposition in sockeye redds, decreasing egg survival. High levels of turbidity and SSC during the sockeye fry emigration period result in reduced sockeye fry survival, fitness, increased gill abrasion, and altered oxygen uptake.

Life stages affected: Adult staging, adult spawning, egg incubation, and emergence and dispersal.

Rationale: High turbidity levels, which are an indicator of SSC, have been recorded in Ozette spawning tributaries, especially Umbrella Creek and Big River (peak values >500 NTU). Peak streamflow and turbidity events are common during the sockeye migration, spawning, and egg incubation periods. In Umbrella Creek, for the duration of the 2005 sockeye migration and spawning period, 85 hours had turbidity values greater than 100 NTU. Elevated turbidity and SSC can have negative behavioral and physiological effects on adult sockeye, including negative effects on predator avoidance, territory selection, mate selection, homing and migration, gill function and integrity, respiration, and blood physiology.

Peak streamflow and turbidity events are slightly less common during the sockeye fry emigration period. During the 2005 sockeye fry emigration period, a total of 15 hours had turbidity values greater than 100 NTU. In 2005, the spawning period was shown to have greater turbidity levels than the fry emigration period. Generally, due to reduced average monthly precipitation, flood events carrying high sediment loads will be less frequent during fry emigration compared to adult spawning. However, high turbidity and sediment levels still occur during emigration. Elevated turbidity and SSC can have negative behavioral and physiological effects on juvenile sockeye, including negative effects on predator avoidance, swimming and emigration efficiency, gill function and integrity, respiration, and blood physiology.

The high road densities in spawning tributaries (averaging >6.0 mi/mi2), extensive clear-cutting (>95 percent of Umbrella Creek and Big River watershed clear-cut at least once), increased channel instability, mass wasting events, and other land use activities (e.g., agriculture) all contribute to elevated turbidity and SSC levels in tributaries. Dozens of observations of sediment inputs violating Washington State Department of Ecology water quality standards have been made during the last decade within the primary sockeye spawning tributaries, but no attempt has been made to quantify the magnitude of increase of turbidity and SSC caused by land use activities. (Note: The impacts of SSC levels on other species may be significantly different from the impacts on adult sockeye.)

Processes and inputs: Sediment inputs, streamflow, and LWD recruitment.

Activities affecting inputs/processes: Activities affecting water quality during tributary residency include past and present logging and road building, floodplain alterations (including agriculture, rural development, bank armoring), and historical wood removal (reduced floodplain connectivity resulting in more fine sediment storage in the active channel rather than on the floodplain).

4.4.2.3 Predation (H#14-Pred)

Hypothesis 14: Predation of sockeye fry by piscivorous fish during emergence, emigration, and dispersal significantly reduces the number of fry rearing in the pelagic zone of the lake. However, predation on adult sockeye and eggs in tributaries occurs at low levels and is not likely a significant limiting factor.

Life stages affected: Adult staging, adult spawning, egg incubation, and emergence and dispersal.

Rationale: Hughes et al. (2002) concluded that there is very little evidence of pre-spawning predation mortality in Umbrella Creek, based on tagging, tracking, genetic sampling, and spawning ground surveys. In 2000, seven adult sockeye tagged with CART tags were tracked in Umbrella Creek and all were observed to have successfully spawned. Egg predation in tributaries has not been thoroughly investigated, but the potential impacts are thought to be low. Hydraulic sampling of sockeye redds conducted in 1998 and 1999 to assess egg survival did not indicate that significant egg predation was occurring in Umbrella Creek. The standing of tributary egg predation as a limiting factor largely remains a data gap.

Estimates of post-release survival for the 1998 brood year Umbrella Creek Hatchery released fingerlings moving downstream from RM 4.8 to RM 0.8 ranged from 74 percent to 40 percent. Burgner (1991) reviewed several studies conducted to determine fry predation rates for riverine spawned sockeye fry emigrating to nursery lakes and found widely ranging values: 63 to 84 percent (Scully Creek, Lake Lakelse, 4-year study), 66 percent (Six Mile Creek, Babine Lake, 1-year study), 13 to 91 percent (Karymaiskiy Spring, Kamchatka Peninsula, 8-year study), and 25 to 69 percent (Cedar River, Lake Washington). Large numbers of predators (cottids, cutthroat, coho yearlings) were captured incidentally in fyke net trapping of natural-origin fry in Umbrella Creek during the spring of 1999. Predators consumed sockeye fry relative to coho fry at a ratio of 8.3 to 1, even though there were many more coho fry available, suggesting that sockeye fry were the preferred prey species during the months of April and May.

Processes and inputs: Processes and inputs affecting predator-prey balance have been altered from pre-European contact conditions.

Activities affecting inputs/processes: Activities affecting or that have affected the predator-prey balance in the Ozette tributaries include introduction of non-native fish species, historical directed Ozette sockeye fisheries that resulted in decreased sockeye abundance, and selective habitat alterations that negatively affected sockeye habitat (resulting in reduced sockeye abundance) but had a negligible effect (or positive effect) on predators' key habitat.

4.4.2.4 Streamflow (H#15-Q)

Hypothesis 15: Natural and anthropogenically influenced streamflow variability (magnitude, frequency, and timing of low and high flows) affects sockeye mortality by: 1) delaying adult migration into tributaries (resulting in more predation, egg retention); 2) limiting where adults spawn in a cross-section (i.e., sequestering spawners in areas where egg scour or desiccation is likely); and/or 3) increasing emigrating fry exposure times in tributaries (affecting predation, water quality).

Life stages affected: Adult migration, adult spawning, egg incubation, and emergence and dispersal.

Rationale: Delayed migration of sockeye into tributaries during October and November has been observed during extreme low base flow conditions and a delay in the onset of the wet season. The population impact of delayed migration because of streamflow is thought to be low, however, because unlike sockeye spawning in shallow water at beaches, sockeye congregating near tributary mouths are more flexible in their holding depths and locations, enabling fish to minimize predator interactions. Climatic variability in precipitation timing is a natural phenomenon that sockeye salmon have adjusted to. However, land use could lower the magnitude of base flows to a currently unknown degree. Under natural conditions, higher sustained base flows may have allowed sockeye to migrate into tributaries earlier in the spawning season. Climate change into the future could alter the timing of the onset of the wet season (i.e., the first few rains), combining with lower base flows to create a more significant impact on migration timing.

Extended periods of high streamflow (caused by high storm frequency and intensity) can shift the distribution of spawning from “normal” positions in the channel to the margins where velocity and depth more closely match the preferred conditions (e.g., Ames and Beecher 2001). When this occurs and is followed by normal or low flows, eggs in redds constructed along the channel margins or in less optimal positions in the channel may experience increased mortality during incubation because of redd dewatering or fine sediment intrusion. Extended dry periods yielding low flows following more or less normal flow conditions can produce the same effect. Conversely, below-average flows during spawning that force fish to spawn low in the channel (thalweg), followed by large flood events, can increase susceptibility to redd scour (Ames and Beecher 2001; Lapointe et al. 2000). Thus, for sockeye spawning in compound channels under variable discharge regimes, there is a tradeoff between spawning low in the cross-section and risking scour mortality versus spawning high along channel margins and risking redd desiccation or sedimentation-related mortality.

Lack of long-term hydrologic datasets in the Ozette Watershed prohibit the exact quantification of any potential changes to hydrology and flow regimes from land use and channel modifications. The high road densities in sockeye tributaries (averaging >6.0 mi/mi^2), extensive clear-cutting (>95 percent of sockeye watersheds clear-cut at least once), and lack of floodplain connectivity (i.e., channelization and wood removal) cumulatively support the hypothesis that hydrologic change has occurred in Ozette tributaries, but with an unknown magnitude. This is consistent with the voluminous literature indicating that water yield changes begin following a significant (10 to 25 percent) reduction of forest vegetation cover, with the highest impacts in conifer forests in high precipitation zones. The quantification of this potential limiting factor remains a data gap.

Sockeye salmon emerge from the spawning gravel in Ozette tributaries from March to May. This is generally a period of decreasing discharge because of reduced precipitation. As discussed above in relation to the timing of adult sockeye migration into the tributaries, climatic variability in precipitation timing and the stochastic nature of weather events are phenomena that sockeye salmon have generally adjusted to under natural conditions and population levels. However, unusually low streamflow and precipitation can affect the rate of sockeye emigration (e.g., spring 2004) and likely their mortality. Tabor et al. (1998) suggested that predation rates were low in most sites studied in the Cedar River during the 1997 fry emigration to Lake Washington because of high streamflow. They found that at mid-channel sites, where velocities were moderate or high, little predation of sockeye salmon was observed. Seasonal droughts and reduced streamflow could be exacerbated by land use changes. These changes may affect the magnitude, but not the timing, of base flows. Land use (including channel modifications) could affect low base flow magnitudes to an unknown degree. Natural conditions with higher sustained base flows may have allowed sockeye to emigrate into Lake Ozette during a shorter time period. Climate change into the future could alter the timing and magnitude of flows needed to transport sockeye fry down into Lake Ozette.

Processes and inputs: watershed hydrology and climate variability.

Activities affecting inputs/processes: logging and road building, agriculture, and other floodplain alterations resulting in reduced floodplain connectivity and function.

4.4.2.5 Holding Pool Habitats (H#16-HP)

Hypothesis 16: Current holding pool frequency and volume, reduced from historical conditions, appear to be adequate in relation to the current numbers of adult sockeye salmon. However, as the tributary population continues to expand, this factor may begin to exert an influence.

Life stages affected: Adult migration and adult spawning.

Rationale: Female sockeye preparing to spawn will frequently be attacked by adjacent territorial females. Therefore, females preparing to spawn will often hold in pools prior to moving onto the spawning grounds (Quinn 2005). Downstream of the primary spawning areas in Umbrella Creek and Big River, holding pool frequency is good or fair in most channel segments; however, some segments in Big River have reduced pool volume because of lack of wood and the resultant sediment aggradation. Other pool attributes (e.g., percent woody cover) have reduced quality in many channel segments within Umbrella Creek and Big River. As tributary sockeye population sizes increase, the quantity and quality of pool habitat will become more important.

Within the primary spawning areas in Umbrella Creek and Big River, holding pool frequency ranges from poor to good depending upon the channel habitat segment. Pool habitat quality (frequency, complexity, depth, size) can be characterized as fair. Once sockeye salmon begin the spawning process, they become territorially focused on protecting their respective redds, and pool habitat becomes much less important than during the holding period. Pool quality within the primary tributary spawning grounds is therefore thought to have a negligible impact on sockeye salmon spawning success.

Processes and inputs: LWD recruitment, sediment inputs, and channel stability.

Activities affecting inputs/processes: Activities affecting holding pool quantity and quality include past and present riparian logging, past and present riparian road building and maintenance, and floodplain alteration (agriculture, rural development, bank armoring, stream-crossings).

4.4.3 Factors Not Likely Limiting Sockeye

The following factors were evaluated and determined not likely to limit sockeye salmon VSP parameters. A brief narrative is included summarizing why each factor is not likely to limit sockeye salmon population viability.

4.4.3.1 Competition (Redd Superimposition)

Within Umbrella Creek, competition for suitable spawning sites and mates is more intense than in Big River and Crooked Creek. In recent years, large numbers (1,000 to 4,000) of spawning sockeye have used habitat in a fairly discrete section of Umbrella Creek (most spawning has been observed in a 2.2-mile-long stream reach). Competition for spawning habitat within this reach can be intense, and redd superimposition plays a significant role in determining the number of fertilized eggs that are ultimately deposited into the spawning gravels to incubate. During the peak spawning period, downstream of mass spawning areas in Umbrella Creek, hundreds of sockeye eggs can be observed along the bottom of the stream or being transported downstream. The degree of redd superimposition likely varies depending upon the number of spawners returning to Umbrella Creek, as well as how they distribute themselves. Redd superimposition at levels occurring in Umbrella Creek likely reduces the overall egg-to-fry survival rate, but net production is not thought to be reduced; that is, if fewer sockeye spawned in Umbrella Creek, the net fry production would be reduced, not increased. However, if sockeye were distributed evenly throughout all suitable habitats, egg-to-fry survival would increase, as would net fry production. Redd superimposition likely has a negligible impact on overall egg-to-fry survival in Big River and Crooked Creek.

4.4.3.2 Interactions with Kokanee

Kokanee-sockeye interactions are thought to be minimal in Umbrella Creek and Big River but common when sockeye are present in Crooked Creek.

Few kokanee spawn in Umbrella Creek. However, sockeye spawning with kokanee-size *O. nerka* in Umbrella Creek have been observed and documented on several occasions. Kokanee spawning in the mainstem of Big River is very rare. A review of nearly 200 spawning ground surveys (1970-2005) conducted in the mainstem of Big River during the kokanee spawning season yielded only one observation of kokanee, and these fish were not observed spawning. The impact of kokanee-sockeye interactions in Umbrella Creek and Big River was rated as negligible in the LFA.

Within Crooked Creek, kokanee abundance is far greater than sockeye abundance. Peak kokanee counts per mile averaged 100-500 during years with complete surveys. Competition and interaction between kokanee and any sockeye present in Crooked Creek is expected to be fairly common. Kokanee spawn timing is slightly earlier than observed sockeye spawn timing, which may act to minimize interaction and gene flow between these populations. Hatchery releases designed to introduce sockeye into Crooked Creek no longer occur because of concerns over sockeye-kokanee interactions and the fact that two groups represent discrete ESUs of *O. nerka*.

4.4.3.3 Research and Monitoring

Spawning ground surveys are conducted approximately every 7 to 10 days within the primary sockeye spawning reaches. Surveyors are trained to identify and record all types of spawning activity, even under difficult or cryptic situations. Surveyors are also trained to avoid walking in areas suitable for spawning and to walk along channel margins and dry bars. Observed redds are flagged on the nearest branch or tree for future reference. Over time, redds can become masked in appearance as a result of algae growth, water depth, or bedload transport. It remains possible that surveyors could still walk or step on redds and crush eggs. However, years of experience and the precautions mentioned above likely keep impacts negligible.

4.4.3.4 DISEASE

See Section 4.2.3.4